Engineering and Construction Division

# PLANNING REPORT ON THE EL YUNQUE HYDROELECTRIC PROJECT

December 18, 1946

PUERTO RICO WATER RESOURCES AUTHORITY
SAN JUAN, PUERTO RICO

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MEMORANDUM

To : Mr. Antonio Lucchetti
Executive Director

From : Carl A. Bock

There is submitted herewith a report on the proposed EL YUNQUE PROJECT for the development of the power resources of the Luquillo Mountain region. The plan in general is similar to the power feature of the proposed dual purpose project which was submitted to the Insular Planning Board on May 27, 1946, except that the location of the power plants is such as to obtain the full utilization of the power head.

Additional studies made since the completion of our report of May 23, 1946 have confirmed our previous conclusions as to the engineering feasibility of this project, and show it to be even more attractive than indicated by our early estimates.

C A Bock
Carl A. Bock
Chief Engineer

Encl.

EL YUNQUE HYDROELECTRIC PROJECT

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## APPENDIX

# INTRODUCTION

The high mountain area of the Luquillo Forest in northeastern Puerto Rico offers promising possibilities of development for power and utilization for water supply. The prolific rainfall, the high power heads obtainable, and the proximity to the metropolitan area of San Juan all combine to favor the development of this power resource.

Data collected by the Water Resources Authority for years past have disclosed exceptionally attractive possibilities of power development by utilizing the full head available. Such a project, similar to the existing Río Blanco plant, could be quickly constructed with a small investment and would provide a limited power output at a low cost.

The engineers of the Authority have felt that the great potential value of this water resource warrants the best efforts towards complete development and multiple-purpose use, and have directed their studies accordingly. In 1942 they proposed a joint development for water supply and power in cooperation with the city of San Juan. This proposal was rejected by the city on the grounds that an adequate water supply could be obtained from another source more quickly and at less cost and without the use of critical materials. The four years that have elapsed apparently find San Juan still lacking a water supply adequate to its expanding needs, and it seemed appropriate to reconsider the advantages offered by a dual-purpose development of the mountain source of Luquillo Forest.

The Authority, therefore, renewed on May 27, 1946 its proposal for such a project based on its latest data and studies, for joint development with the Aqueduct Service, designed for complete utilization of this water source both for power and water supply. It was believed that in this manner of joint participation in the development the people of Puerto Rico would enjoy, at maximum economy, the benefits thus afforded by two of the most important products affecting their health and general welfare. Such a plan was described in our report of May 23, 1946, and was submitted to the Insular Planning Board. In case this joint project should fail of consummation, then the Authority desires to proceed with a single-purpose development, as the need for additional hydro-generated power is becoming urgent. Plans for power development alone have been studied in detail, and pertinent data concerning them are summarized in the present report.

This report has been prepared by Robert C. Price and Rafael Nevares Jr., Head Planning Engineer and Senior Engineer, respectively, of the Engineering and Construction Division.

## SUMMARY

The proposed project provides for the collection, by means of pipe lines and conduits, of the run-off of 11.6 square miles of drainage area located on the northern and western slopes of the Luquillo mountain range, a region of the highest rainfall on the Island. This run-off yield will be impounded in a seasonal storage and regulating reservoir of 6,300 acre-feet capacity located on the Cubuy river, a headwater tributary to the Canovanas river. From the reservoir the waters will be directed downstream through a pressure conduit along the right bank of the Cubuy river for a distance of some 9,000 feet, and then dropped through a 7,000-foot penstock and pressure tunnel to an upper power plant along-side the Canovanas river and thence to a second plant at a lower elevation.

The normal flow (average year) available will be 72 cfs, the critical flow (driest period on record) being 51 cfs. Normal power production will be approximately 55,000,000 kilowatt hours annually, of which some 39,000,000 will be firm energy (based on the most critical period on record.)

Preliminary estimates indicate the project will cost approximately $5,600,000. On this basis the cost of normal hydro-produced energy delivered to the switchyard feeders will be 4.97 mills per kilowatt-hour.

Under this plan of development of this region for power only the entire available working head will be utilized, so that the tailrace waters could not be transmitted to San Juan by gravity flow.

Other possibilities for development of this region for power only, including the possibility of partial development and of diverting the flow by means of a tunnel into the Gurabo River basin, have been investigated but on final analysis have proved less desirable than the proposed El Yunque Project.

## THE PROJECT PLAN

The proposed project is located along the northwestern border of the Caribbean National Forest Area twenty miles northeast of San Juan and eight miles south of the town of Canóvanas.

It is proposed to build a combination earth and rock-fill dam on the upper reach of the Cubuy river creating a reservoir of 6,300 acre-ft capacity to permit seasonal storage and annual flow regulation in utilizing the run-off of 11.6 square miles of the Luquillo mountain area. The drainage area at the dam site is 3.5 square miles and the remaining 8.1 square miles are located on the northern slopes of the mountain, the run-off of which will be diverted to the penstock or reservoir by pipe lines and conduits. A shaft spillway will be constructed at the extremity of one of the left arms of the reservoir and discharging through the divide into the Canovanillas river basin. The flow for power will be provided by both the reservoir and pipe conduit from the north watershed by joining in such manner that the stored water will be used to regulate the flow. A low pressure pipe line will be directed from the dam around the west slope of the mountain to meet the gravity flow conduit 9,000 feet from the dam. From here the entire flow will be conveyed by high pressure penstock and tunnel to Power Plant No. 1 located on the right bank of the Canóvanas River, some 20,000 feet from the dam measured along the stream bed. From the tailrace of this power plant the water will be conveyed by means of a 60" gravity pipe along the right bank of the Canóvanas River some 20,000 feet to Power Plant No. 2 to develop additional energy.

This plan will make available a net head of 1050 feet for the generation of hydro-electric energy in Plant No. 1, and of 200 feet in Plant No. 2, using all available water for this purpose. The installed capacity of Plant No. 1 will be 10,000 kilowatts in two units of 5,000 kilowatts each, operating at 50 per cent plant factor, and 2,000 kilowatts in Plant No. 2.

## Statistical Data

### General

| | |
|---|---|
| Location - 20 miles southeast of San Juan | |
| Drainage area (square miles) | 11.6 |
| Streams Utilized - Cubuy, Rio Grande, Espiritu Santo, Gurabo | |
| Estimated total annual run-off (acre-feet) | 68,500 |
| Run-off utilized, average year (acre-feet) | 52,300 |
| Average utilization (per cent) | 76 |
| Regulated flow, average year, (cfs) | 72 |
| Regulated flow, critical period (cfs) | 51 |
| Water available for water supply: | |
| Average year, (mgd) | 46.5 |
| Average year (acre-feet) | 52,300 |
| Average year (cubic meters) | 64,500,000 |
| Critical period - 3 months (mgd) | 33 |

### Dam

| | |
|---|---|
| Type | Combined earth rock-fill |
| Maximum height (feet) | 124 |
| Crest length (feet) | 1,100 |
| Free board (feet) | 7 |
| Elevations (feet - msl) | |
| River bed | 1,300 |
| Crest of dam | 1,424 |
| Outlet works | 1,344 |
| Stream diversion by | Tunnel |
| Length of diversion tunnel (feet) | 400 |
| Section and size of tunnel | Horse-shoe 10-foot |
| Estimated Cost | $ 1,532,000 |

### Spillway

| | |
|---|---|
| Type | Overflow chute or shaft and tunnel |
| Diameter of lip (feet) | 54 |
| Section of tunnel | Round |
| Diameter of tunnel (feet) | 18 |
| Designed flood (second-feet) | 15,000 |
| Flood head on crest (feet) | 7 |
| Elevations - (feet - msl) | |
| Spillway Crest | 1,410 |
| Maximum flood level | 1,417 |
| Outlet tunnel invert | 1,350 |
| Tunnel slope | 0.02 |
| Estimated Cost | $ 240,000 |

### Reservoir

| | |
|---|---|
| Area at max. flood pool (acres) | 210 acres |
| Length (feet) | 6,000 feet |
| Elevations (feet - msl) | |

| | |
|---|---|
| Maximum flood pool | 1,417 |
| Maximum power pool | 1,410 |
| Minimum power pool | 1,344 |
| Drawdown (feet) | 66 |
| Volumes (acre-feet) | |
| Total at maximum flood pool elev. | 7,750 |
| Total at maximum power pool elev. | 6,300 |
| Total at minimum power pool elev. | 300 |
| Dead storage | - 300 |
| Usable storage | 6,000 |
| Surcharge storage | 1,450 |

Pipe Lines and Tunnels

| | |
|---|---|
| Lengths of gravity-flow pipes (feet) | |
| 20-inch diameter (concrete) | 1,500 |
| 24-inch diameter (concrete) | 14,400 |
| 36-inch diameter (concrete) | 5,000 |
| 42-inch diameter (concrete) | 6,000 |
| 48-inch diameter (concrete) | 18,800 |
| 60-inch diameter (concrete) | 19,600 |
| Lengths of pressure pipe (feet) | |
| 48-inch diameter (concrete) | 9,000 |
| 60-inch diameter (concrete) | 2,400 |
| 50 to 42-inch diameter (steel) | 1,560 |
| Lengths of tunnels (feet) | |
| 6-foot gravity flow | 700 |
| 6-foot pressure | 3,300 |
| Cost of pipe lines and tunnels | $2,225,000 |

Power Plant No. 1

| | |
|---|---|
| Type of turbines | Impulse |
| Gross head available (feet) | 1,100 |
| Net operating head (feet) | 1,050 |
| Elevation tailrace (feet - msl) | 310 |
| Installed capacity (kilowatts) | 10,000 |
| Normal power in kw. (100% P.F.) | 5,200 |
| Installed plant factor (per cent) | 50 (approx.) |
| Average annual energy (kwh) | 45,000,000 |
| Prime power (kw.) | 3,600 |
| Estimated Cost | $1,000,000 |

Power Plant No. 2

| | |
|---|---|
| Type of turbines | Reaction |
| Gross head available (feet) | 220 |
| Net operating head (feet) | 200 |
| Elevation tailrace (feet - msl) | 90 |
| Installed capacity (kilowatts) | 2,000 |
| Normal power in kw. (100% P.F.) | 1,000 |
| Installed plant factor (per cent) | 50 (approx.) |
| Average annual energy (kwh) | 10,000,000 |
| Prime power (kw.) | 900 |
| Estimated Cost | $200,000 |

## DESCRIPTION OF THE AREA

### General

The drainage area of the project includes 11.6 square miles of the upper northern and western slopes of the Luquillo Mountain Range, being on the opposite side of the mountain slopes supplying the run-off for the Rio Blanco Hydro-electric Development. The El Yunque Project, together with a future proposed extension to the Rio Blanco Project, will thus utilize the entire upper drainage area of the Luquillo mountain system, except the Mameyes River which represents only about 10 per cent of the total usable area.

Although almost all the drainage area is located within the Caribbean National Forest Reserve, the only part of the proposed project works within the Reserve is a portion of the northern slope diversion pipe line, and the extreme upper reach of the reservoir.

The drainage area above the proposed storage dam and diversions, except for some farm tracts in the lower vicinity of the western and southern sections, is a virgin and sparsely inhabited forest area. It is an ideal and well protected catchment basin for potable water supply, and within a short distance from the capital and largest city in the Island.

### River Systems

The watershed of the proposed project includes the head-water-drainage areas of the Espiritu Santo, Rio Grande, and Canovanas Rivers to the north; and the Cubuy and Gurabo Rivers to the east of the central storage reservoir on the Cubuy River.

The Espiritu Santo and Rio Grande Rivers flow north to a junction east of the town of Rio Grande, and thence north to the Atlantic Ocean. The Cubuy and upper Canovanas flow northwest and form a junction about

8000 feet below the dam site, and thence (as the Canovanas River) almost due north until a confluence is made with the Loiza River north of the town of Canovanas. The upper reach of the Gurabo flows southeast for a few kilometers, thence turns almost due west and flows into the Loiza west of the town of Gurabo.

These streams are all small and their profiles, except the Gurabo, downstream to the point of utilization, are fairly flat but the drop below the diversion line is abrupt and steep, The Gurabo profile is steep from its beginning to the diversion point.

Topography

The terrain included within the proposed project area is irregular, varying from steep slopes near the summit of the mountain peaks to fairly uniform and more gentle slopes down along the proposed diversion lines. The drainage area includes some of the highest peaks to be found along the Insular divide; two of which are El Yunque and El Toro, whose elevations are 3496 and 3532, respectively.

Geology

The geology of the project area is not unlike that occurring in other parts of the interior of the Island. The rocks are all of volcanic origin. According to the publication "Geology of Puerto Rico" by Mr. H.A. Meyerhoff, the western part of the project area was at one time the seat of the largest volcano contributing to the formation of the Island.

The dam site and power plant are located in an area of Upper Cretaceous pyroclastic rocks, including massive andesite tuffs and agglomerate, and associated conglomerates. For further geologic description of the dam site refer to a reconnaissance report by Mr. R. A. Lawrence, page 19 of this report.

The spillway is located in an area of intrusive porphyries, chiefly andesitic, which have invaded the Upper Cretaceous sedimentary and pyroclastic rocks.

## PRELIMINARY INVESTIGATIONS

### Early Studies and Reports

On January 14, 1942, the Puerto Rico Water Resources Authority was requested by the Federal Works Agency under approval of the President of the United States to make a survey and preliminary plans for meeting the water supply needs of the San Juan metropolitan area, and to present preliminary cost estimates and specifications for developing an adequate source of supply.

Pursuant to this request studies were started immediately, and in July 1942, after investigating various possible sources, the Water Resources Authority reported its findings, recommending the development of the waters of the high mountain area of the Luquillo Forest as the most appropriate source of supply. This area is in the region of the highest rainfall of the Island, in virging forest and sparsely inhabited, providing an ample source of relatively unpolluted mountain water, soft and of excellent quality. It has the further advantage of being capable of utilization for the development of hydro-electric energy in conjunction with its development for use as a water supply, with resulting economies for both uses. This plan, however, was rejected by the engineers of the Federal Works Agency and by the City on the contention that it would take too long to build, was too costly, and involved some critical materials for its construction.

Due to the pressing need for additional power sources, the Water Resources Authority has continued its surveys and studies in this area more in detail. These extended studies, and the discovery of a reservoir site high in the mountains which can control the run-off from the area, have disclosed a highly profitable plan for utilizing these waters for power development alone,

The results of the early studies and investigations made in the Caribbean National Forest Area, including other pertinent data, were compiled in a detailed report dated January 21, 1943.

Recent Field Investigations

The El Yunque Project lies about 8 miles south of the town of Canovanas, on the Cubuy river and edging the southwestern fringe of the El Yunque mountains. The proposed project is accessible by two roads; #43 from the Canovanas end and El Verde road from the Rio Grande end. A preliminary field reconnaissance of the proposed project was made during the later part of December 1945. Engineering surveys were begun on January 3, 1946 and foundation explorations at the dam site were started during the first week of February 1946.

In order to have a preliminary check of the reservoir area as computed in the office from U. S. G. S. topographic sheets, the survey of the reservoir flow line was given priority.

The vertical control of all surveys was tied in with the vertical control established in the Island by the United States Geological Survey. Permanent hubs have been established at the dam site, and along the line of diversion waterways from the dam site up to the proposed El Verde diversion dam.

Other survey work completed includes development of topographical plans of the dam and spillway sites; preliminary alignment surveys of the grade-conduit lines and surveys of the penstock and pressure pipe lines.

Foundation explorations at the dam site have been completed. Five holes were drilled on the right abutment, four on the left abutment, and three along the diversion tunnel line. All dam site holes were drilled upstream from the axis line. The overburden showed complete weathering down to foundation rock. Average overburden on the right abutment is 50 feet and on the left abutment 15 feet. The rock is unweathered and of andesitic origin.

Earth-borrow and rock-quarry sites have been reconnoitered and explored. Preliminary estimates and field investigations indicate that the material is suitable for the construction of the dam and that it is available in sufficient quantities. A laboratory report has been made on the materials available for the construction of the dam.

Determination of the Water & Power Available

In determining the water available, it has been necessary to use rainfall records as a base for run-off quantities. It is recognized that this method of stream flow evaluation may lead to error in estimating the

flow available. However, these estimates have been based on the flows recorded at similar mountain divide where dependable rainfall and run-off records are available for a long period of time, and therefore it is believed that they show expected flows within a reasonable margin of error.

Rainfall Studies: Rainfall records within and nearby the area are short. Rain gages installed at different places in the headwaters of the streams within this and in nearby areas are given below, and their location is shown in the General Plan, Drawing No. 1.

| Station | Years of Record | Average Rainfall |
|---|---|---|
| El Verde Km. 13.1 | 2 years- 1944-45 | 125 inches |
| El Verde Dam Site | 3 years- 1943-45 | 150 inches |
| Cubuy No. 1 | 4 years- 1942-45 | 128 inches |
| Cubuy No. 2 | 3 years- 1943-45 | 104 inches |
| La Mina * | 6 years- 1936-41 | 188 inches |

* Discontinued in 1942.

The nearest station outside the area for which long rainfall records are available is the Rio Blanco Station at El. 1800, located at the headwaters of the Hicaco River in the southern slope of the mountain range. At this station continuous rainfall records are vailable for a period comprising the last 16 years.

To determine if the short period of record of the five stations tabulated above represents approximately an average rainfall period, the following analysis on the records of the Rio Blanco Sta. El. 1800 is hereinafter made:-

| Period | Ave. for Period | 16 Yrs. Average | Ave. of Period 16 Yrs. Ave. |
|---|---|---|---|
| 1944-45 | 151.98" | 152.94" | 99.5% |
| 1943-45 | 157.81" | 152.94" | 103.0% |
| 1942-45 | 156.46" | 152.94" | 102.2% |
| 1936-41 | 151.82" | 152.94" | 99.3% |

This comparison shows that the short period of records of these stations represent approximately the average rainfall to be expected over a long period.

To simplify the computations, the total drainage area of this project has been divided into four sections, and the average annual rainfall at these sections has been estimated from these records and comparisons as follows:

| Area No. | Description | Area in sq. mi. | Estimated Ave. Rainfall |
|---|---|---|---|
| 1 | D. A. at Cubuy | 3.50 sq. mi. | 125" |
| 2 | D. A. at stream lying north of Cubuy Dam drainage area | 1.73 sq. mi. | 130" |
| 3 | D.A. at headwaters of Grande and Espiritu Santo Rivers and adjacent streams | 5.39 sq. mi. | 170" |
| 4 | D.A. at headwaters of Juncos River in the south side of the main divide | 1.00 sq. mi. | 135" |
| | Total = | 11.62 sq. mi. | |

<u>Stream Flow Studies</u>: In order to obtain information relative to the minimum flows in the extreme dry periods, as well as an average yield to be expected from this area, the records of other areas have been studied, including that of the Rio Blanco Project.

The Rio Blanco Hydro-electric Project consists of a run-of-river plant which takes its waters from the area lying on the southern slope of the Luquillo Mountain Range, immediately adjacent to the headwater area of the Espiritu Santo River, which is part of the proposed El Yunque development.

Its drainage area is similar in altitude, temperature, vegetation, soils, ground slopes and size (6.705 sq. miles), to the area of the proposed headwater diversions, and subject to an average annual rainfall of about 153 inches (Rio Blanco Sta. El. 1800). Monthly and daily records of the flows thru this plant are available for the period 1935-45. These records have been found useful in determining minimum flows during the dry seasons, but unfortunately are of little use in estimating average yields, due to lack of storage facilities which cause frequent undetermined spillings at the diversion sites during rainy seasons.

In the following table are given the average monthly flows recorded at Rio Blanco Plant during the critical dry season year 1935-36 and the estimated minimum flows that would be available in the streams included in this project during a critical dry season:

| MONTH | Recorded Flows at Rio Blanco Plant During Dry Season of 1935-36 D.A. -6.705 sq.mi. | Recorded Flows per sq. mi. of Drainage Area | Estimated Minimum Run-off of stream included in this project D.A. - 11.62 sq. mile |
|---|---|---|---|
| December | 25.9 cfs. | 3.86 cfs. | 45.0 cfs. |
| January | 25.0 cfs. | 3.73 cfs. | 43.5 cfs. |
| February | 16.7 cfs. | 2.48 cfs. | 28.9 cfs. |
| March | 10.7 cfs. | 1.59 cfs. | 18.5 cfs. |
| April | 10.8 cfs. | 1.61 cfs. | 18.8 cfs. |
| Total | 89.1 cfs. | 13.17 cfs. | 154.7 cfs. |
| Average | 17.8 cfs | 2.63 cfs. | 31.0 cfs. |

In order to determine the average yields of the streams supplying this project, rainfall and run-off records of the following mountain

streams on the northern side of the Insular divide, with drainage areas ranging from one and one half to eight square miles, have been studied for comparison:

| Stream | Altitude | Drainage Area |
|---|---|---|
| Toro Negro River | 2900 ft. | 1.57 square miles |
| Matrullas River | 2400 ft. | 4.42 square miles |
| Vacas River | 2400 ft. | 6.60 square miles |
| La Plata River | 1780 ft. | 7.92 square miles |

The conditioning factors of altitude, temperature, vegetation, soils, ground slopes and size of drainage area are similar enough between there recorded streams and the streams within the National Forest Reserve as to warrant the use of the same average run-off factor. The results of this study indicate that an average run-off of 40 acre-feet per square mile per inch of rainfall may be expected from such mountain areas. (See Table No. 1 in the Appendix). As a result of this comparison the average run-off of the four sections of drainage area supplying the Cubuy Reservoir has been estimated as follows:

| Area No. | Drainage Area | Estimated Average Rainfall | Estimated Ave. Run-off |
|---|---|---|---|
| 1 | 3.50 sq. mi. | 125 inches | 17,500 Acre-ft. |
| 2 | 1.73 sq. mi. | 130 inches | 9,000 Acre-ft. |
| 3 | 5.39 sq. mi. | 170 inches | 36,600 Acre-ft. |
| 4 | 1.00 sq. mi. | 135 inches | 5,400 Acre-ft. |
| Total | 11.62 sq. mi. | | 68,500 Acre-ft. |

Usable Flow: About 75% of the total drainage area of the El Yunque Project would be diverted by means of small diversion dams and conduits. To determine approximately the percentage of the total run-off that may be utilized from this area, the automatic stream flow records obtained at El Verde Station during the wet season of this fiscal year have been correlated and studied to obtain the duration and frequency of occurrence of each flow.

The average rainfall over the 2.13 square miles of drainage area available at el Verde Station has been computed at 170 inches and the average annual run-off at 20 cfs based on an average annual yield of 40 acre-feet per square mile per inch of rainfall. (Exhibit #2 shows the percentage of time which each flow occurred, recorded between July to December, 1945). From this flow duration curve the percentage of the total run-off that could be diverted with conduit capacities of 10, 20, 30, and 40 cfs were computed and found to be 43, 62, 71.5 and 77 per cent, respectively. In the same exhibit is shown the percentage of utilization for different conduit capacities in cfs per square mile as determined from the flow duration curve of El Verde Station. It shows that with a conduit capacity of 15 cfs per sq. mile of drainage area a utilization factor of 70 per cent could be obtained. As this study is based on records during the rainy season it is estimated that the results obtained would have a reasonable margin of safety if used on a yearly basis.

The designed capacity for all diversion conduits has been estimated on the basis of 15 cfs per square mile of drainage area and therefore the utilization factor for diverted areas has been estimated at 70 per cent.

The utilization factor for the reservoir area has been estimated at 95 per cent after allowing 5 per cent in losses for evaporation, leakage,

and spillings.

The following table gives the estimated average annual utilized run-off from this area:

| Area No. | Estimated Ave. Annual Run-off | Estimated Utilization Factor | Estimated Annual Utilized Run-off |
|---|---|---|---|
| 1 | 17,500 Acre ft. | 95% | 16,600 Acre ft. |
| 2 | 9,000 Acre ft. | 70% | 6,300 Acre ft. |
| 3 | 36,600 Acre ft. | 70% | 25,600 Acre ft. |
| 4 | 5,400 Acre ft. | 70% | 3,800 Acre ft. |
| Total | 68,500 Acre ft. | | 52,300 Acre ft. |

As shown by this table the total expected annual yield available at the power plants would be 52,300 acre feet which is equivalent to a uniform annual flow of 72.0 cfs, which is the regulated flow in an average year.

Regulation Obtained for Prime Flow: The reservoir created by the proposed dam with the maximum power pool at elevation 1410 will provide 6000 acre feet of usable seasonal storage. This storage will supply an average flow of 20 cfs during five months of dry season. Adding to this flow the minimum average inflow to the reservoir during this period, estimated at 31 cfs gives a total minimum regulated outflow from the reservoir of 51.0 cfs during the most critical dry season. (See Exhibits Nos. 3, 4, and 5).

Energy Production: The average head losses due to drawdown in the reservoir and to friction in the conduit and penstock of Plant No. 1 is estimated at 50 feet giving an average net head in the plant of 1,050 feet. Under this head the usable flow of 52,300 acre-feet (72.0 cfs) will yield an average annual energy output of 45,000,000 kwhr. at the upper plant. This flow will be augmented by the Canóvanas River to an average annual flow of 80 cfs. for utilization in Plant No. 2 which, under an average net head of 200 feet, will develop an annual energy output of 10,000,000 kwhr at this lower plant. The proposed usable storage of 6,000 acre feet represents about 6,200,000 kwhr of stored energy.

The minimum regulated outflow of 51.0 cfs will yield under an average total net head of 1,250 feet in both plants a dependable energy output of 3,300,000 kwhr per month, which is considered the prime power.

## PROJECT LAYOUT AND DESIGN CONSIDERATIONS

### The Storage Dam

Three dam sites were considered; the one as shown herein and two others about 1,000 and 2,000 feet upstream respectively. No survey and foundation explorations were carried out on these upstream sites, as field reconnaissances and office studies were sufficient to eliminate

both of them from the present scheme of the proposed development.

The site shown herein is located where the river flows in a rock gorge or canyon about 15 feet deep along the downstream foundation area of the dam. The exposed bed rock in the stream bed on both banks some 20 feet above the river is a hard, massive and durable andesite. Near the upstream toe location the rock is overlaid with from 15 to 20 feet of boulders and gravel.

The following excerpt from "Geologic Reconnaissance of Several Dam Sites in Puerto Rico", by Robert A. Lawrence, Geologist - U.S. Geological Survey - Dated December 14, 1945, describes the geology at the upper dam site, 2000 feet upstream from the one finally selected. However, the geology of the two sites is quite similar.

> "The Cubuy site, on Cubuy River about 6-1/2 miles southwest of Rio Grande and 20 miles southeast of San Juan, was examined very briefly on December 5, 1945. No detailed topography is available, and no drilling or other exploratory work has been done yet. The site is at the boundary of two quadrangles (Yunque and Gurabo) for which advance sheets on 1/10,000 scale are available. A dam of about 80 feet height is proposed for this site. This will require a total length of about 1000 feet as both abutments are relatively gentle-sloping ridges projecting into the valley.
>
> Rock is exposed in the stream bed and in scattered outcrops up the lower 20 or 30 feet of the right bank. Most of it somewhat weathered and covered with moss, so that no truly fresh samples were obtained. All rock seen is a coarse volcanic agglomerate or breccia with a very fine grained greenish matrix. There is no obvious bedding and the massive outcrops are cut by many joints, but weathering does not appear to have selected any of these sites as particularly favorable zone.
>
> From the weathered condition of the few exposed rocks, and the gentle slopes and small width of the abutment ridges, it seems inevitable that there will be a deep overburden and low rock surface. However, the site seems quite suitable for a concrete spillway section with earth embankments. Because of the peculiar advantage afforded by the striking difference in altitude of the Canovanas (of which Cubuy is a tributary) and Canovanillas rivers, this project appears to be worthy of further consideration, and core drilling is recommended."

Two types of dams were considered for the proposed site, (1) a concrete gravity at the central section with overflow spillway flanked with earth fill abutments, and (2) a combined earth and rock-fill with the spillway remotely located from the dam. Cost estimates, together with the problems of foundation, design layout, and availability of construction materials heavily favored the earth and rock-fill and consequently this type was selected.

A general plan and sections of the proposed dam are shown on Drawing No. 4, appended hereto. The crest length will be 1100 feet at elevation 1424, and the maximum height along the axis will be 124 feet. The section, as shown, will include a modified rolled-earth embankment flanked with heavy rock blankets on either slope. Stability studies have not been made, but due to the favorable topography for such a section, it is believed that a stable and impervious dam can be constructed along the lines of this design. Low concrete cut-off walls would be provided along the foundation where rock is exposed and the overburden depth is not economically prohibitive. Where overburden is deep, as along the spur ridge on the right abutment, a wide trench will be excavated parallel to the axis and filled with impervious clay, well compacted. Stream diversion during construction will be provided by a 10-foot tunnel about 400 feet long through the right abutment ridge. This tunnel will also be used to house the pressure conduit from the intake leading to the power plant.

<u>The Spillway</u>

The spillway will be located along the rim of the reservoir about 1,100 feet upstream from the dam site (See Drawings Nos. 3 & 5). This saddle is located in the divide between the Cubuy and Canovanillas river basins

in the right side of the reservoir created by the dam. Drilling explorations have been made at this location to determine the depth of the rock foundation. This drilling shows good rock foundation at around elevation 1405, and it is estimated that a side-channel overflow spillway may be the most economical structure. If the rock should be found deeper than expected, then a "Morning Glory" shaft spillway, as shown in Drawing No. 5. is indicated. In any event, it is estimated that either type of spillway structure finally adopted would be safe and economical.

The spillway will be designed for a maximum capacity of 15,000 cfs.

The Reservoir

The lake created by the Cubuy Dam will extend 6,000 feet upstream and will cover an area of about 200 acres at the spillway level. The total volume that would be stored at the maximum flood pool elevation (1417) will be 7,750 acre feet, proportioned as follows:

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Dead storage | from | El. | 1310 | to | El. | 1344 | (msl) | = | 300 | acre feet |
| Usable | " | " | 1344 | " | " | 1410 | " | = | 6000 | " " |
| Surcharge | " | " | 1410 | " | " | 1417 | " | = | 1450 | " " |

The heavy tropical vegetation covering almost all the 3.5 square miles of the watershed of the dam will prevent erosión, and therefore it is believed that silting in the reservoir will be negligible.

The Diversion Waterways

The General Plan and the General Profile Drawings Nos. 1 & 2, shows the principal features of the proposed diversion system. This system will provide, by conduit diversion an additional drainage area of 7.81 square miles from the headwaters of the streams lying along the north slope of the mountain divide. (See Drawing No. 3 areas Nos. 2 & 3).

It is also proposed to divert 1.0 square mile of drainage area of the headwaters of the Gurabo River into the Cubuy Dam drainage area by means of a 24" diameter grade conduit about 7,500 feet long. (See area No. 4, Drawing No. 3).

The proposed diversion system will require the construction of 20 small diversion dams, 2 main diversion dams, 47,000 lineal feet of precast-concrete pipe, and 700 lineal feet of tunnel. The pipe sizes required will be 1,500 lineal feet of 20-inch diameter, 14,400 lineal feet of 24-inch diameter, 5,000 lineal feet of 36-inch diameter, 6,000 lineal feet of 42-inch diameter and 18,800 lineal feet of 48-inch diameter. The tunnel will be a 4 x 6-foot section, and it is believed that lining, except at the portals, will not be necessary.

The flow will be carried from the reservoir to the Power Plant No. 1 through a waterway consisting of 9,000 lineal feet of 48-inch pressure pipe, 1,900 lineal feet of 60-inch pressure pipe, 3,300 feet of 7-foot diameter standard horse-shoe section tunnel, and 1,560 lineal feet of 48-inch steel penstock. From the tailrace of Plant No. 1 the flow will be conveyed through 19,600 lineal feet of 60-inch diameter grade concrete conduit and 500 lineal feet of 60-inch pressure concrete pipe to Plant No. 2.

As shown in the General Profile, Drawing No. 2, the surge shaft is connected at the junction of the 48" pipe line coming from the reservoir and the 60" diameter pipe syphon crossing the upper Canóvanas River. The surge shaft opening will serve as an inlet to the waters diverted from areas Nos. 2 & 3 and it is set at an elevation high enough to force these waters into the reservoir in case the flow exceeds the capacity of the plant.

The diversion tunnel will be used for the conduit intake and will be located on the right abutment of the dam some 65 feet below the spillway level.

The Power Plants

Both power plants will be located on the right bank of the Canóvanas River. Power Plant No. 1 will have its tailwater discharging into an intake structure from which the water will be delivered to the conduit and penstock leading to Power Plant No. 2. The installed capacity at Plant No. 1, based on a 50 per cent plant factor, will be about 10,000 kilowatts which under an average flow of 72 cfs and an average net head of 1,050 feet will give an average annual generation of 45,000,000 kw-hrs. The equipment will include two horizontal single overhung impulse wheels of 7,000 HP each directly connected to a 6,300 kva capacity generator.

The installed capacity at Plant No. 2 will be about 2,000 kilowatts, which with an average flow of 80 cfs and an average net head of 200 feet will produce an average annual generation of 10,000,000 kw-hrs. The equipment will consist of one horizontal reaction wheel developing 3,000 HP directly connected to a 2,700 kva capacity generator.

Both power plants will be automatically operated by remote supervisory control from the Monacillo's Substation, which is located near Río Piedras.

## CONSTRUCTION FEATURES

### Access

A paved highway, road No. 43 from Canóvanas to Gurabo, is partly constructed extending along the left bank of the Canóvanas River for a distance of about 7 miles up to a point about 1-1/2 kilometers from the damsite and passing very near the plant site. An unpaved road starting at this point continues upstream along the left bank of the Canóvanas River, passes along the left abutment of the dam and crosses the river at a short distance upstream and continues to the east until it meets El Verde Road running almost parallel and very near to the proposed conduit line coming from Espiritu Santo River diversion site. This road will give access to the diversion waterway and only some access trails will be required for this feature. An access road to the tunnel portal and some access trails to the pressure pipe line will be required.

### Camp and Plant Site

An excellent location is available along the road and nearby the dam site for such camp and plant facilities that will be required. This area is downstream from the dam and, therefore, will not be subject to flooding when the reservoir is filling.

### Construction Equipment

If the final design studies indicate the most suitable types of hydraulic structures to be as shown herein, the problems of the required construction equipment will be simplified. Equipment for the dam will largely involve excavating and hauling units for earth and rock, which may be shovels and dump trucks. The earthwork may be handled with scraper-loaders, since there is sufficient room and suitable ground slopes for maneuvering such units. The quantity of concrete required, outside of the

pipe lines, will be small and it is possible that a small portable plant will provide adequate production capacity. The precast concrete pipes will require small units of excavating equipment plus hauling units, preferably cars on narrow gage track.

Construction Materials

Investigations are now underway on the materials available for construction. Preliminary earth testing has been done in a small laboratory set up in Canóvanas. Some investigations have been completed on locations of a rock quarry to provide fill material for the dam. It appears that the best location for this rock material is on the left bank of the Cubuy River some 2,000 feet downstream from the dam site at about the same elevation as the crest of the proposed dam. No sand or gravel deposits have been located within the project area. Sand may have to be transported from the Loiza river bed down along the north coastal plains.

Power for Construction

It will be necessary to construct about 8 miles of 38 kv power line from the Canóvanas Substation to the dam and plant sites for construction purposes. This line will pass thru a region densely populated and may be constructed under the Rural Electrification Program of the Authority.

## Construction Program

It is estimated that the construction period will be about 29 months. If the dam were started at the beginning of a dry season there would be three dry seasons available for the placing of the earth portion of the embankment.

## Recreational Features

The Cubuy Reservoir will be located in an area surrounded by typical tropical vegetation and the climate is moderately cool through the whole year making this region very inviting for the development of a summer resort similar to the one established near El Yunque Peak in the adjacent area to the east.

# ECONOMIC CONSIDERATIONS

The estimate of cost shown at the end of this report, is based on the type of structures shown in Drawings Nos. 1 to 6 inclusive. The cost of transmission lines has not been included. Unit costs shown in the estimate are more than double the actual costs of such work performed on the Island 12 years ago. Cost estimating is extremely difficult due to the uncertainty of times in the post-war period.

## Economics of Power Production

The value of the power produced will not be affected by the operating limitations of supplying water in more or less continuous output

for water supply consumption. For this reason, the plants will have additional value in peaking capacity, and therefore a somewhat lower plant factor (0.50) which corresponds to a relatively higher installed capacity, is justified.

The method used in analyzing the power economics of the project consists of transforming the total output to a firm continuous production output through the addition of sufficient steam reserve. The economic feasibility of the project is then appraised by comparing this cost of production with the equivalent cost of production in an alternate base load steam plant which will produce the same firm output as the project under consideration.

Estimated Production: From rainfall records at Rio Blanco Sta. El. 1800, the average dry season rainfall (from December to April inclusive) at this area has been estimated at about 33% of the total annual rainfall. (See Table No. 2)

Assuming the average usable run-off to be in the same proportion as the rainfall, then:

The average inflow into the reservoir during the five months of dry season = 33% of 52,300 Acre ft. = 17,250 Acre ft. Adding to this inflow the 6,000 acre ft. provided by the storage, gives an average regulated outflow from the reservoir during an average dry season of 23,250 acre ft. The average inflow into the reservoir during the seven months of wet season = 67% of 52,300 acre ft. = 35,050 acre ft. Subtracting the 6,000 acre feet needed to fill the reservoir, gives an average regulated outflow from the reservoir during an average wet season of 29,050 acre feet.

The minimum outflow from the reservoir estimated at 51.0 cfs is equi-

valent to a total outflow from the reservoir during a critical dry season of 5 months of 15,300 acre feet.

The average flow from the additional area diverted into the lower plant is estimated at 8 cfs or 5800 acre ft per year. 33 per cent of this, or 1900 acre feet, are assumed to be diverted during the average dry season (5 months) and the balance, or 3900 acre feet, during the average wet season (7 months). During the critical dry season, an average flow of 2 cfs or 600 acre feet in the 5-month period is estimated to be available from this area.

From the above figures the following productions are obtained:

PLANT NO. 1

Estimated average net head ........................... 1050 feet

Estimated average production per acre foot - $1050 \times \frac{590}{725}$ ........................... 855 kwhr

Estimated average monthly output during an average wet season - $\frac{29,050}{7} \times 855$ .................. 3,550,000 kwhr

Estimated average monthly output during an average dry season - $\frac{23,250}{5} \times 855$ .................. 4,000,000 kwhr

Estimated average monthly output during a critical dry season - $\frac{15,300}{5} \times 855$ .................. 2,620,000 kwhr

Steam standby capacity needed at 70% plant factor to prime up all energy to 4,000,000 kwhr per month - $\frac{4,000,000 - 2,620,000}{730 \times 0.7}$ .................. 2,660 kw

Average annual prime energy output
4,000,000 x 12 ....................................48,000,000 kwhr

Average annual energy produced by hydro
(3,550,000 x 7) + (4,000,000 x 5) ..................45,000,000 kwhr

Average annual energy produced by steam ............. 3,000,000 kwhr

PLANT NO. 2

Estimated average net head............................ 200 feet

Estimated average production per acre foot - $200 \times \frac{610}{725}$ .................................... 169 kwhr

Estimated average monthly output during an average wet season - $\frac{32,950}{7} \times 169$ .................. 800,000 kwhr

| | |
|---|---|
| Estimated average monthly output during an average dry season - $\frac{25,150}{5}$ x 169 .................. | 850,000 kwhr |
| Estimated average monthly output during a critical dry season - $\frac{15,900}{5}$ x 169 .................. | 540,000 kwhr |
| Steam standby capacity needed at 70% plant factor to prime up all energy to 850,000 kwhr per month - $\frac{850,000 - 540,000}{730 \times 0.7}$ ...................... | 600 kw |
| Average annual prime energy output 850,000 x 12 .................................... | 10,200,000 kwhr |
| Average annual energy produced by hydro - (800,000 x 7) + (850,000 x 5) ............. | 9,850,000 kwhr |
| Average annual energy produced by steam ........... | 350,000 kwhr |

Cost of Energy from both Plants

Annual Charges ( Prime Energy)

| | | |
|---|---|---|
| 1. | Value of capacity required to prime up the entire generation 3,260 kw at $20.00............ | $ 65,200 |
| 2. | Variable fuel and other costs 3,350,000 kwhr at 4.5 mills | 15,100 |
| 3. | Interest at 3% + depreciation at 1.6%; $5,600,000 x .046 .. | 257,600 |
| 4. | Operation and Maintenance ... | 15,000 |
| | Total annual charges, excluding taxes .... | $ 352,900 |

Annual Charges (All hydro energy)

| | | |
|---|---|---|
| 1. | Interest at 3% plus depreciation at 1.6%; 5,600,000 x .046 ..... | 257,600 |
| 2. | Operation and Maintenance ...... | 15,000 |
| | Total annual charges excluding taxes ........ | $ 272,600 |

Therefore, the cost of prime energy would be

$$\frac{352,900}{58,200,000} = 6.07 \text{ mills, and}$$

the actual cost of all hydro-electric energy generated would be:

$$\frac{272,600}{54,850,000} = 4.97 \text{ mills}$$

Cost of Energy (If produced by steam)

Annual Charges:

| | | |
|---|---|---|
| 1. | Capacity value at 50% plant factor $\frac{58,200,000}{8760 \times 0.5} \times \$20$ .................. | 266,000 |
| 2. | Variable fuel and other costs 58,200,000 kwhr x 4.5 mills ....... | 262,000 |
| | Total annual cost of same energy by steam ...... | 528,000 |

Therefore, the cost of the same quantity of prime energy if produced by steam, would be:

$\frac{528,000}{58,200,000}$ = 9.10 mills, or 3.03 mills higher

than the cost of prime energy estimated for this project.

The above analysis indicates that the development of the El Yunque project for power production alone is economically justifiable. It is estimated that the project for power alone will cost the Water Resources Authority \$ 5,600,000 as compared to an allocated cost of \$ 3,000,000 for the power feature in the multiple-purpose project for power and water supply, as proposed in our report of May 23, 1946.

The average energy production of this single purpose project is 55,000,000 kilowatt hours annually as compared to a normal production of 41,000,000 kilowatt hours for the multiple-purpose project. The firm energy output of the project, based on the most critical period on record, is 39,000,000 kilowatt hours, which also compares favorably with a firm output of 29,000,000 kilowatt hours for the combined project.

The freedom from operating limitations of supplying water in a continuous output for water supply consumption allows the plants to be operated under a lower plant factor and enhances the value of these plants for providing increased peaking capacity.

The dependable capacity value of the plant in the multiple-purpose project, corresponding to a firm energy output of 29,000,000 kilowatt hours at a plant factor of 0.60, is 5500 kilowatts. The corresponding capacity value of the plants in this project for power alone, equivalent to a firm energy output of 39,000,000 kilowatt hours at a plant factor of 0.50 is 9000 kilowatts.

The value of the additional energy and the increased peaking capacity obtained in this project may be evaluated as follows:

| | |
|---|---|
| Annual value of 14,000,000 kwhrs at $ .0045 ................. | $ 63,000 |
| Annual value 3500 kw increased capacity at $ 20.00 .............. | 70,000 |
| Total ........... | $133,000 |

The increased contribution of this project to the Authority's electric system is therefore estimated to be worth $ 133,000 annually, which capitalized at the rate of 4.6 per cent, justifies an allowable investment of $ 2,900,000 for obtaining these benefits.

## ADDENDUM

### Irrigation Possibilities

Although this project has been referred to as a single-purpose project for the development of hydro-electric power, studies are being made to use the waters from the tailrace of Power Plant No. 2 for irrigation of the coastal plains both to the east and west of the Canovanas river.

There are some 15,000 acres which can be supplied with irrigation water at a reasonable cost. If these waters are sold for as low as $2.00 per acre-foot the annual income would be more than $100,000. It is estimated that the benefits to the sugar cane growers might be an increase of around 10 tons per acre, or some 150,000 tons, which at $10 per ton would represent an increased gross income of $1,500,000.

An irrigation system for this area would guarantee the sugar cane crop. It is reported that in 1945 the cane growers in this locality lost more than $1,000,000 because of a reduction in yield due to a drought. Three such droughts have occurred in the last 20 years. These facts indicate that the proposed project has a considerable potential value to the area for irrigation as well as for power.

# A P P E N D I X

## EL YUNQUE PROJECT

### PRELIMINARY COST ESTIMATE

| FEATURE | UNIT | QUANTITY | UNIT COST | AMOUNT | ESTIMATED COST |
|---|---|---|---|---|---|
| **PRELIMINARY** | | | | | |
| Engineering Surveys | L. S. | — | — | 40,000 | |
| Foundation Explorations | L. S. | — | — | 20,000 | $ 60,000 |
| **GENERAL CHARGES** | | | | | |
| Construction Buildings | L. S. | — | — | 40,000 | |
| Permanent Operators Quarters | L. S. | — | — | 10,000 | |
| Construction Roads | Km. | 10 | 5,000 | 50,000 | |
| Road Relocation | " | 1 | 10,000 | 10,000 | |
| Access Roads | L. S. | — | — | 25,000 | 135,000 |
| **LAND ACQUISITION & CLEARING** | | | | | |
| Lands Purchased | Acre | 250 | 100 | 25,000 | |
| Lands Cleared | Acre | 200 | 30 | 6,000 | |
| Right-of-way & Damages | L. S. | — | — | 10,000 | 41,000 |

(Cont.)

EL YUNQUE PROJECT

PRELIMINARY COST ESTIMATE (Cont.)

| FEATURE | UNIT | QUANTITY | UNIT COST | AMOUNT | ESTIMATED COST |
|---|---|---|---|---|---|
| **DAM & APPURTENANCES** | | | | | |
| Stream Diversion | L. S. | — — | — — | 50,000 | |
| Excavation - Earth | Cu.Yd. | 40,000 | $ 1.00 | 40,000 | |
| Excavation - Rock | " " | 1,000 | 3.00 | 3,000 | |
| Embankment - Earth | " " | 175,000 | 1.20 | 210,000 | |
| Embankment - Transition | " " | 75,000 | 1.60 | 120,000 | |
| Embankment - Rock | " " | 250,000 | 2.00 | 500,000 | |
| Concrete - Core Walls | " " | 500 | 20.00 | 10,000 | |
| Concrete - Wave Wall | " " | 800 | 30.00 | 24,000 | |
| Intake Structure | L. S. | — — | — — | 25,000 | |
| Valve House & Equipment | L. S. | — — | — — | 35,000 | |
| Foundation Treatment | L. S. | — — | — — | 13,000 | $1,030,000 |
| **SPILLWAY (Morning Glory Type)** | | | | | |
| Excavation - Unclassified | Cu.Yd. | 25,000 | 1.50 | 37,500 | |
| Excavation - Rock | " " | 5,000 | 10.00 | 50,000 | |
| Concrete - Tunnel | " " | 1,400 | 30.00 | 42,000 | |
| Concrete - Shaft | " " | 300 | 50.00 | 15,000 | |
| Concrete - Weir & Apron | " " | 300 | 25.00 | 7,500 | |
| Grouting | L. S. | — — | — — | 3,000 | |
| Tunnel Outlet Portal | L. S. | — — | — — | 5,000 | 160,000 |

(Cont.

# EL YUNQUE PROJECT

## PRELIMINARY COST ESTIMATE (Cont.)

| FEATURE | UNIT | QUANTITY | UNIT COST | AMOUNT | ESTIMATED COST |
|---|---|---|---|---|---|
| **DIVERSION WATERWAYS** | | | | | |
| Low Pressure Grade Pipe 20"ϕ | Ln. Ft. | 1,500 | $ 4.00 | 6,000 | |
| " " " " 24"ϕ | " " | 14,000 | 4.50 | 63,000 | |
| " " " " 36"ϕ | " " | 5,000 | 7.00 | 35,000 | |
| " " " " 42"ϕ | " " | 6,000 | 8.50 | 51,000 | |
| " " " " 48"ϕ | " " | 18,800 | 11.00 | 207,000 | |
| " " " " 60"ϕ | " " | 19,600 | 16.00 | 313,600 | |
| Tunnel - 6' x 4' | " " | 700 | 40.00 | 28,000 | |
| Small Diversion Works | Each | 20 | 2,000 | 40,000 | |
| Small Diversion Dams | " | 2 | 10,000 | 20,000 | |
| Desilting Works | L.S. | — — | — — | 10,000 | 773,600 |
| **PRESSURE PIPE & PENSTOCK** | | | | | |
| Concrete pipe - 48"ϕ at from 50 to 100 lb. | Ln. Ft. | 9,000 | 25.00 | 225,000 | |
| Concrete Pipe 60"ϕ at 150 lb. | " " | 2,400 | 40.00 | 96,000 | |
| Pressure Tunnel - 6 diameter | " " | 3,300 | 60.00 | 198,000 | |
| Surge shaft tunnel - 6' diameter | " " | 1,200 | 60.00 | 72,000 | |
| Steel Penstock 50" to 40" | " " | 1,560 | 60.00 | 94,000 | |
| Surge Shaft | " " | 250 | 120.00 | 30,000 | 715,000 |

(Cont.)

EL YUNQUE PROJECT

PRELIMINARY COST ESTIMATE (Cont.)

| FEATURE | UNIT | QUANTITY | UNIT COST | AMOUNT | ESTIMATED COST |
|---|---|---|---|---|---|
| POWER PLANT NO. 1 | | | | | |
| Power Plant Building | L. S. | — — | — — | 160,000 | |
| Turbines | Kw. | 10,000 | 12.00 | 120,000 | |
| Generators | " | 10,000 | 13.00 | 130,000 | |
| Misc. Auxiliary Equipment | " | 10,000 | 12.00 | 120,000 | |
| Switch Yard | " | 10,000 | 12.00 | 120,000 | |
| P. H. Crane | L. S. | — — | — — | 13,000 | 663,000 |
| POWER PLANT NO. 2 | | | | | |
| Power Plant Building | L. S. | — — | — — | 54,000 | |
| Turbines | Kw. | 2,000 | 12.00 | 24,000 | |
| Generators | " | 2,000 | 13.00 | 26,000 | |
| Misc. Auxiliary Equipment | " | 2,000 | 12.00 | 24,000 | |
| Switch Yard | " | 2,000 | 12.00 | 24,000 | |
| P. H. Crane | L. S. | — — | — — | 5,000 | 157,000 |

| | |
|---|---|
| TOTAL DIRECT COST | $3,734,600 |
| INDIRECT COST, 25% | 933,700 |
| CONTINGENCIES, 25% | 933,700 |
| ESTIMATED TOTAL COST OF PROJECT | $5,602,000 |

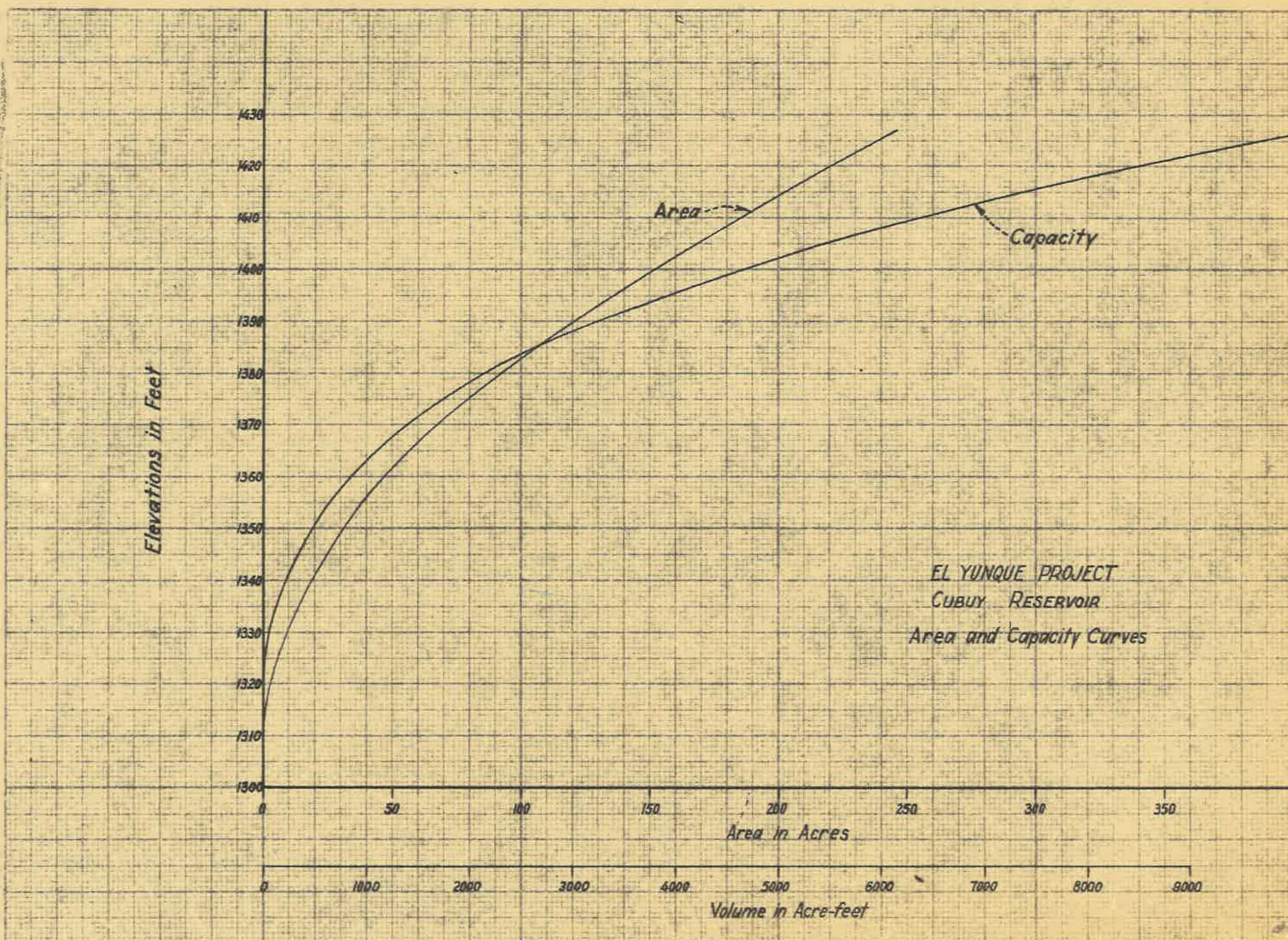

EL YUNQUE PROJECT
CUBUY RESERVOIR
Area and Capacity Curves
Area
Capacity
Elevations in Feet
1300
1310
1320
1330
1340
1350
1360
1370
1380
1390
1400
1410
1420
1430
Area in Acres
0
50
100
150
200
250
300
350
Volume in Acre-feet
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

EXHIBIT NO. 1

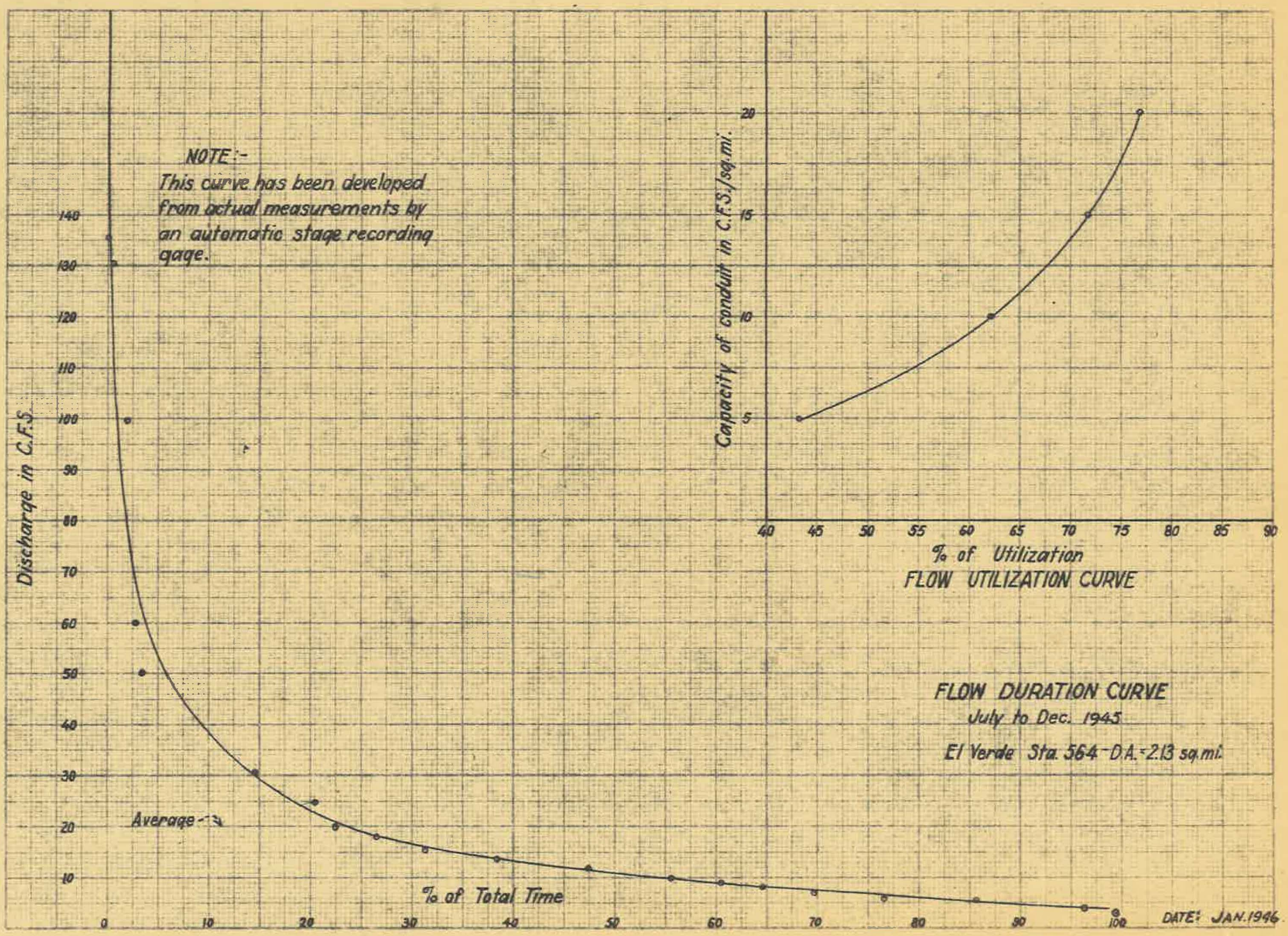

NOTE:-
This curve has been developed from actual measurements by an automatic stage recording gage.
Discharge in C.F.S.
140
130
120
110
100
90
80
70
60
50
40
30
20
10
Average
% of Total Time
0
10
20
30
40
50
60
70
80
90
100
Capacity of conduit in C.F.S./sq.mi.
20
15
10
5
40
45
50
55
60
65
70
75
80
85
90
% of Utilization
FLOW UTILIZATION CURVE
FLOW DURATION CURVE
July to Dec. 1945
El Verde Sta. 564 - D.A. = 2.13 sq.mi.
DATE: JAN. 1946

EXHIBIT NO. 2

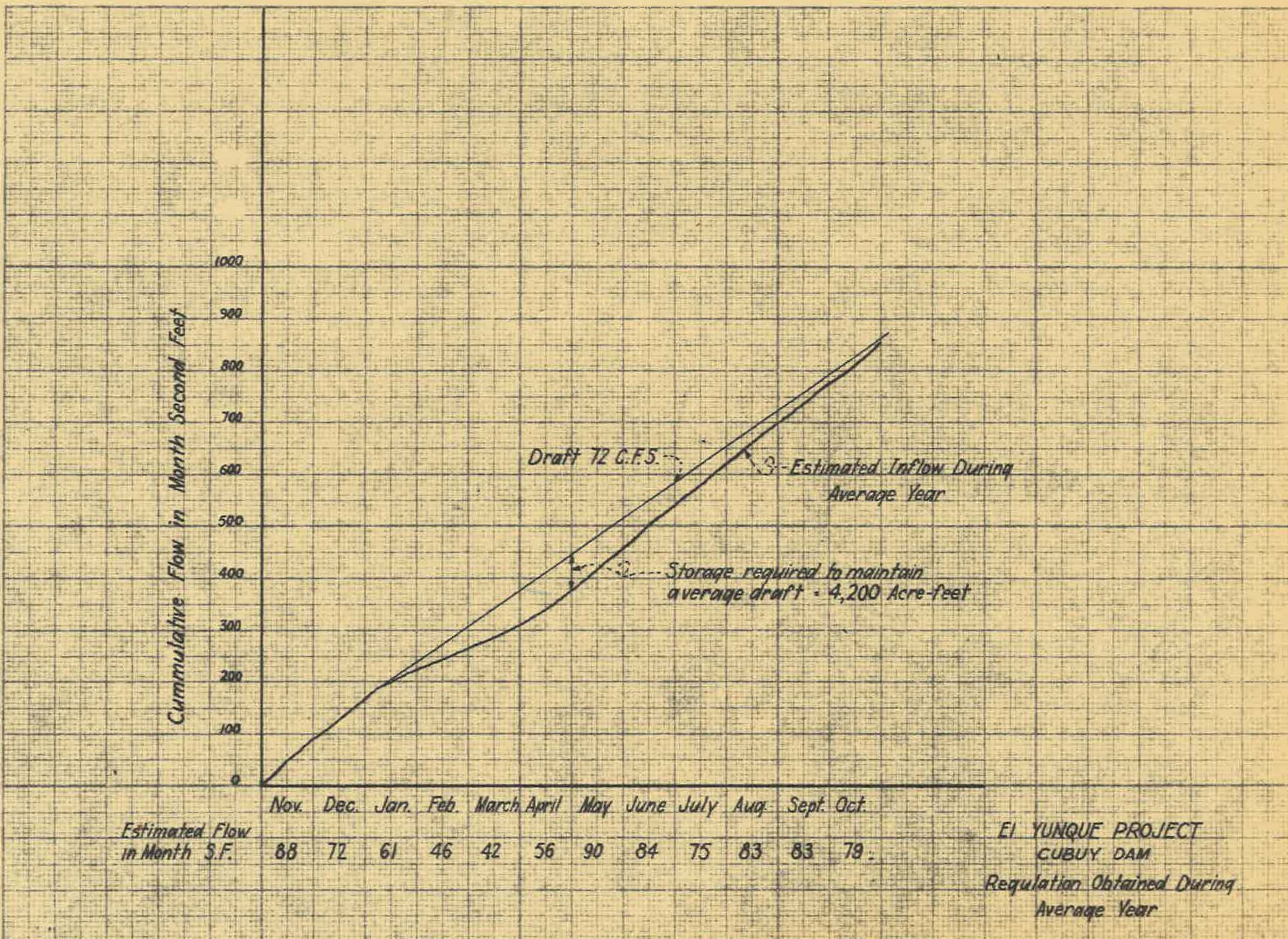

Cummulative Flow in Month Second Feet
1000
900
800
700
600
500
400
300
200
100
0
Draft 72 C.F.S.
Estimated Inflow During Average Year
Storage required to maintain average draft = 4,200 Acre-feet
Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct.
Estimated Flow in Month S.F.
88 72 61 46 42 56 90 84 75 83 83 79
El YUNQUE PROJECT
CUBUY DAM
Regulation Obtained During Average Year

EXHIBIT NO. 3

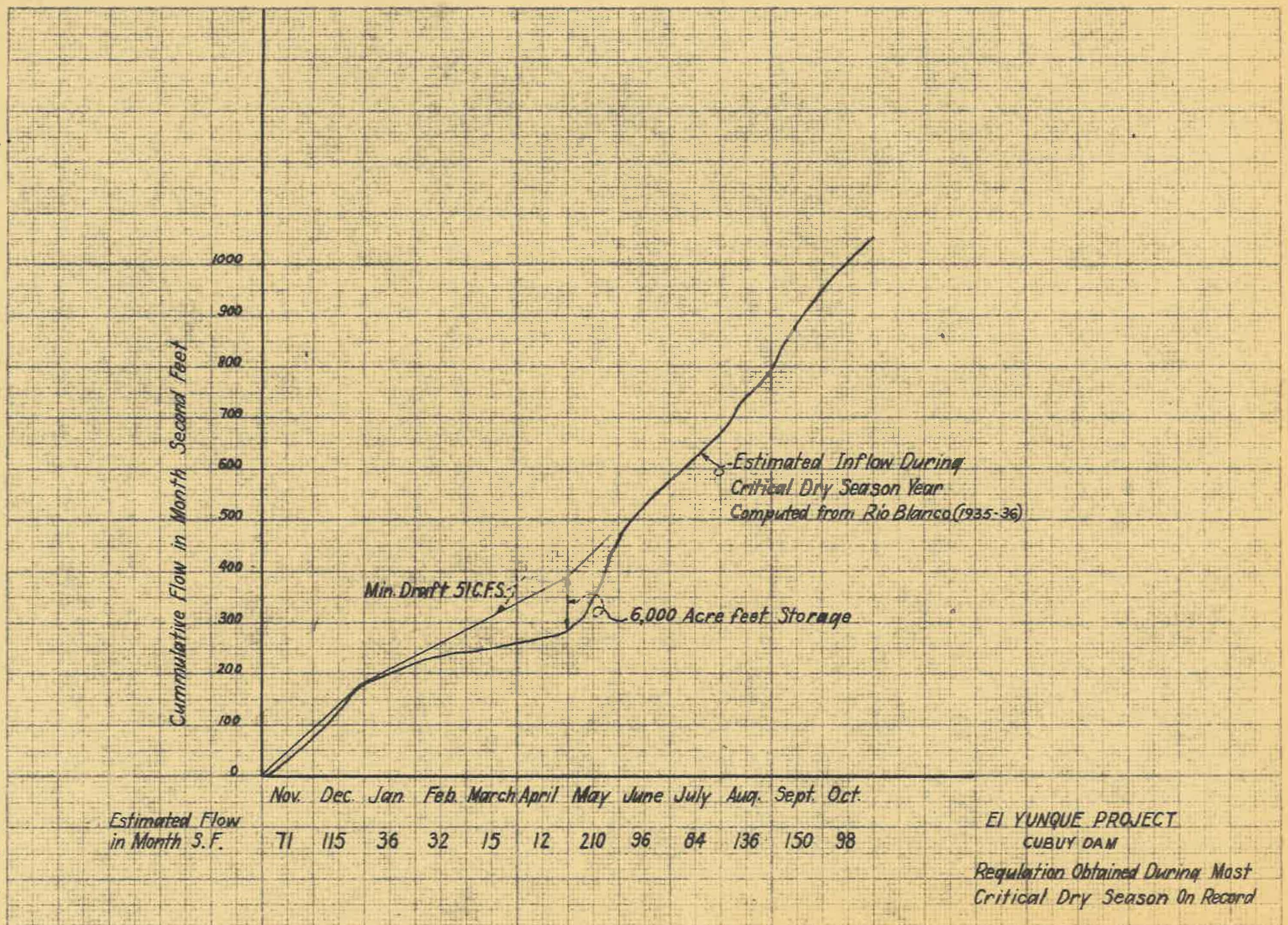

Cummulative Flow in Month Second Feet
0
100
200
300
400
500
600
700
800
900
1000
Nov.
Dec.
Jan.
Feb.
March
April
May
June
July
Aug.
Sept.
Oct.
Estimated Flow in Month S.F.
71
115
36
32
15
12
210
96
84
136
150
98
Min. Draft 51 C.F.S.
6,000 Acre feet Storage
Estimated Inflow During Critical Dry Season Year Computed from Rio Blanco (1935-36)
El YUNQUE PROJECT
CUBUY DAM
Regulation Obtained During Most Critical Dry Season On Record

EXHIBIT NO. 4

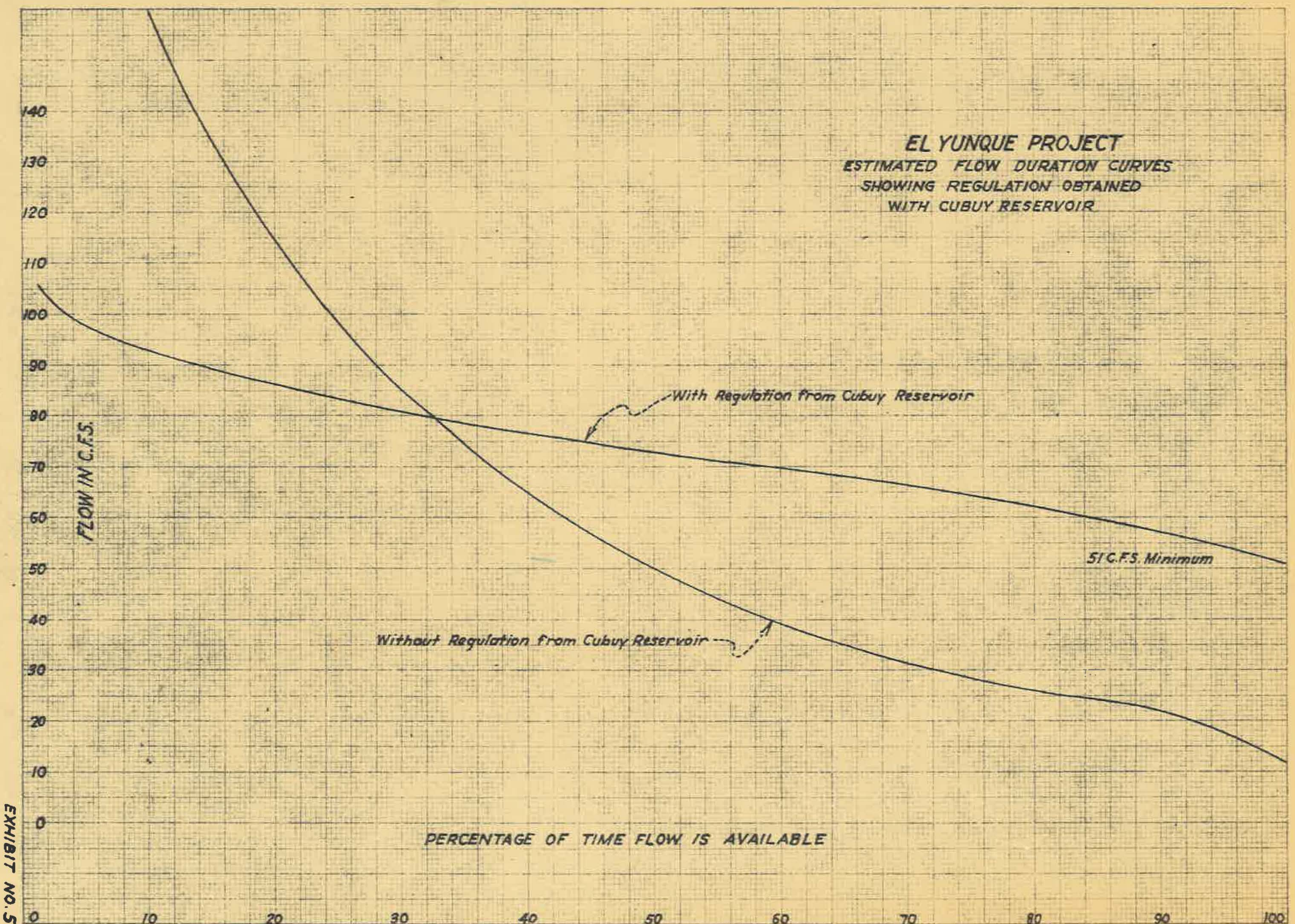

EL YUNQUE PROJECT
ESTIMATED FLOW DURATION CURVES
SHOWING REGULATION OBTAINED
WITH CUBUY RESERVOIR
With Regulation from Cubuy Reservoir
Without Regulation from Cubuy Reservoir
51 C.F.S. Minimum
FLOW IN C.F.S.
PERCENTAGE OF TIME FLOW IS AVAILABLE
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100

EXHIBIT NO. 5

Table I

MOUNTAIN STREAMS

Average Recorded Rainfall & Runoff

| Streams | Elev. | Drainage Area in Sq. Mi. | Years of Record | Average Yearly Rainfall in inches | Average Yearly Run-off in Ac. Ft. | Average yearly Ac. Ft. per sq. mile per inch of rainfall | Coefficient of Runoff |
|---|---|---|---|---|---|---|---|
| Toro Negro River (at Guines Res.) | 2900 | 1.57 | 14 | 105.66 | 7205 * | 43.43 | 81.80% |
| Matrullas River | 2400 | 4.42 | 14 | 85.16 | 16,397 * | 43.57 | 82.00% |
| Vacas River | 2400 | 6.60 | 16 | 94.70 | 21,900 ** | 35.04 ** | 65.80% |
| La Plata River (at Carite Res.) | 1780 | 7.92 | 34 | 81.30 | 31,268 * | 48.50 | 91.00% |
| | | | | | | Ave. | 80.15 |

* Runoff in these streams were measured as inflows to storage reservoirs by recording elevations of water in reservoirs and spillway discharges. They include peaks which would not be recorded by weirs or other methods.

** These records do not include large peaks which were not measured by gaging station.

**TABLE NO 2**

Rainfall Records - Rio Blanco 1800 Ft.

----

| Year | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1921 | ---- | ---- | 13.23 | 6.21 | 11.65 | 8.59 | 20.49 | 9.90 | 10.15 | 13.32 | 11.41 | 5.96 | |
| 1922 | 15.14 | 14.81 | 17.75 | 7.43 | 7.24 | 13.41 | 12.86 | 14.36 | 16.08 | 13.86 | 10.83 | 21.94 | 165.71 |
| 1923 | 8.60 | 5.01 | 7.38 | 14.92 | 6.48 | 17.27 | 9.53 | 13.81 | 10.30 | 15.38 | 7.27 | 14.26 | 130.21 |
| 1924 | 11.59 | 12.73 | 3.32 | 10.71 | 26.37 | 12.19 | 10.75 | 15.86 | 14.63 | 10.71 | 20.40 | 15.06 | 164.32 |
| 1925 | 5.92 | 7.91 | 6.00 | 10.27 | 7.10 | 9.77 | 11.38 | 9.13 | 13.59 | 10.53 | 16.80 | 2.74 | 111.14 |
| * 1929 | | | | | | | | | | 5.56 | 16.46 | 10.39 | |
| 1930 | 24.31 | 5.73 | 5.38 | 11.18 | 9.01 | 8.60 | 9.41 | 11.39 | 13.02 | 9.23 | 18.67 | 7.29 | 133.22 |
| 1931 | 9.98 | 14.92 | 4.21 | 17.98 | 22.70 | 22.58 | 14.82 | 14.33 | 19.55 | 18.94 | 20.75 | 12.13 | 192.89 |
| 1932 | 12.32 | 2.42 | 10.43 | 5.90 | 17.23 | 19.75 | 11.04 | 12.22 | ---- | 14.59 | 16.08 | 11.13 | 147.11 |
| 1933 | 9.16 | 4.73 | 13.17 | 4.79 | 27.93 | 15.35 | 10.96 | 11.75 | 18.55 | 10.51 | 17.78 | 14.03 | 158.73 |
| 1934 | 7.55 | 3.94 | 8.83 | 6.10 | 9.74 | 11.99 | 15.15 | 16.37 | 12.65 | 8.32 | 12.25 | 21.42 | 135.31 |
| 1935 | 7.19 | 14.08 | 7.56 | 4.36 | 13.99 | 13.10 | 9.92 | 9.49 | 14.11 | 16.82 | 12.39 | 19.98 | 142.99 |
| 1936 | 6.34 | 5.50 | 1.08 | 2.72 | 36.26 | 16.67 | 14.66 | 23.78 | 26.18 | 16.91 | 9.41 | 18.37 | 177.86 |
| 1937 | 26.29 | 3.41 | 3.56 | 9.97 | 7.99 | 7.07 | 6.24 | 22.42 | 7.62 | 18.64 | 17.92 | 8.45 | 139.58 |
| 1938 | 10.13 | 12.44 | 9.50 | 5.45 | 9.27 | 25.11 | 9.39 | 12.71 | 16.41 | 13.61 | 31.12 | 14.39 | 169.56 |
| 1939 | 6.74 | 5.91 | 8.46 | 12.35 | 14.54 | 9.26 | 10.39 | 13.59 | 17.42 | 10.51 | 19.93 | 11.82 | 140.92 |
| 1940 | 5.00 | 14.54 | 5.31 | 7.56 | 20.51 | 15.54 | 8.98 | 10.25 | 10.19 | 20.78 | 17.10 | 15.03 | 150.79 |
| 1941 | 6.98 | 1.28 | 4.22 | 9.79 | 17.52 | 12.35 | 20.20 | 15.01 | 11.06 | 10.03 | 11.47 | 12.29 | 132.20 |
| 1942 | 11.69 | 9.40 | 5.18 | 21.63 | 10.16 | 19.00 | 16.00 | 10.53 | 11.00 | 7.63 | 19.82 | 10.28 | 152.32 |
| 1943 | 12.93 | 6.80 | 10.48 | 13.05 | 20.95 | 15.28 | 13.12 | 19.61 | 11.82 | 25.88 | 8.30 | 11.26 | 169.48 |
| 1944 | 8.64 | 6.09 | 2.75 | 6.89 | 13.94 | 26.00 | 20.31 | 20.90 | 19.00 | 19.27 | 10.16 | 13.00 | 166.95 |
| 1945 | 4.82 | 10.01 | 6.47 | 15.63 | 17.03 | 8.76 | 18.07 | 13.77 | 13.76 | 10.76 | 9.41 | 3.00 | 131.49 |
| Sums | 211.57 | 161.66 | 153.92 | 204.89 | 327.61 | 307.58 | 273.67 | 301.18 | 287.07 | 301.79 | 335.73 | 274.22 | |
| Means | 10.57 | 8.08 | 7.33 | 9.76 | 15.60 | 14.65 | 13.03 | 14.34 | 14.35 | 13.72 | 15.26 | 12.46 | 149.15 |

Dry [illegible] 12.46 + 10.57 + 8.08 + 7.33 + 9.76 = 48.20 = 32.31% of total.
W[illegible] 15.60 + 14.65 + 13.03 + 14.34 + 14.35 + 13.72 + 15.26 [illegible] = 67.69% of total.

* No reco[illegible]

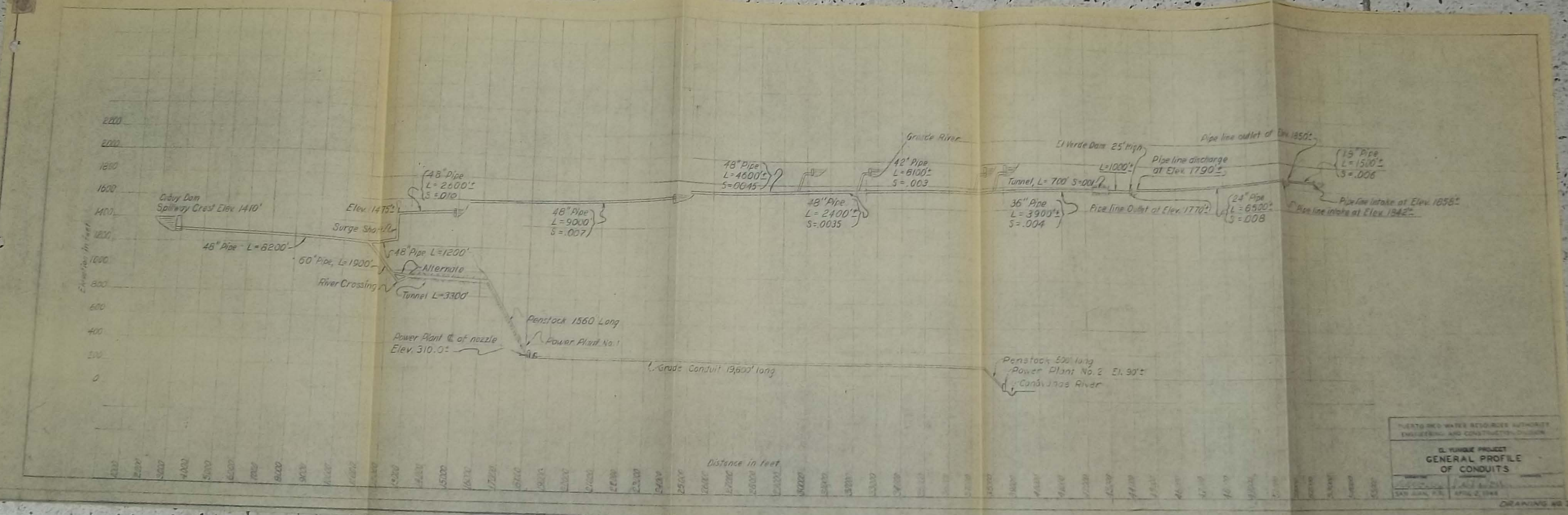
TABLE NO. 3

Rainfall Records - La Mina

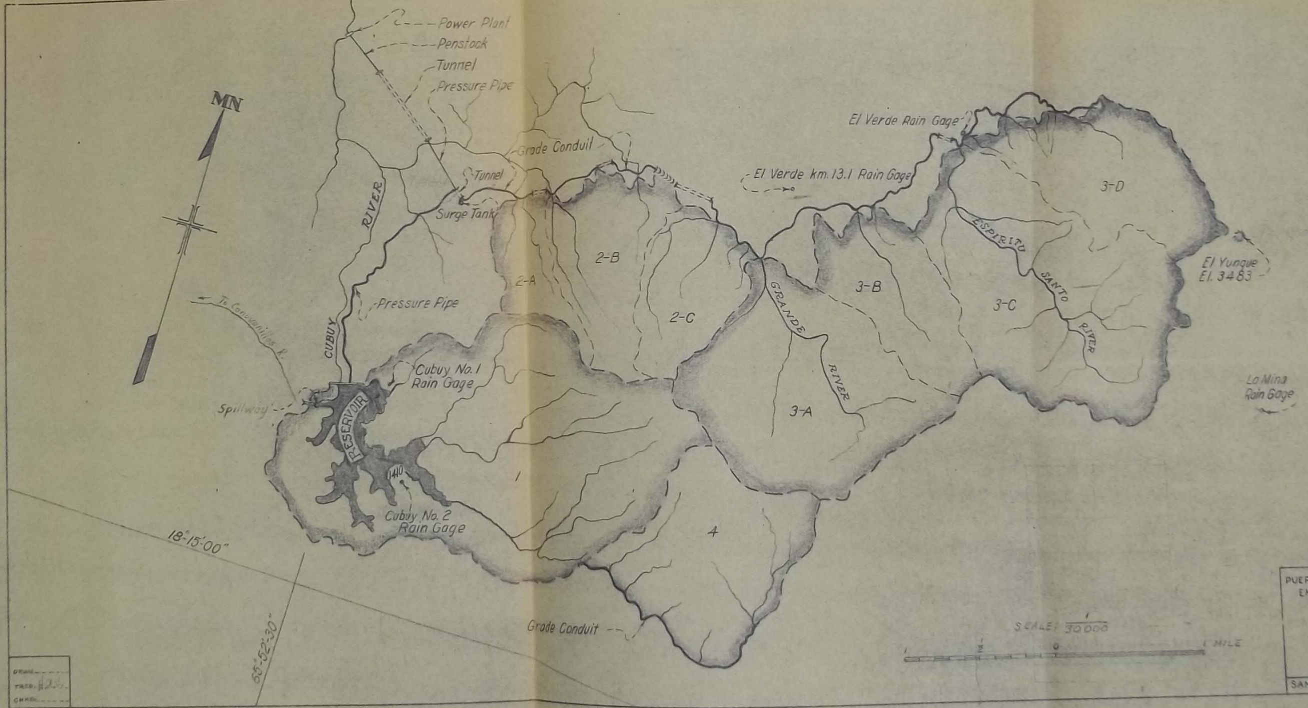
--------

| Year | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1935 | 9.43 | 19.96 | 7.08 | 7.27 | 18.21 | 21.10 | 17.70 | 14.71 | 17.82 | 23.65 | 19.58 | 26.67 | 203.18 |
| 1936 | 9.37 | 7.12 | 3.79 | 3.01 | 40.40 | 19.52 | 19.86 | 36.61 | 29.12 | 37.17 | 15.19 | 32.63 | 253.79 |
| 1937 | 39.75 | 8.53 | 5.02 | 11.44 | 3.38 | 11.86 | 10.68 | 19.89 | 9.07 | 18.79 | 20.07 | 12.37 | 170.85 |
| 1938 | 12.39 | 11.00 | 12.92 | 9.44 | 14.33 | 31.93 | 11.91 | 18.91 | 19.42 | 14.60 | 35.76 | 16.09 | 208.70 |
| 1939 | 8.54 | 7.42 | 10.94 | 8.29 | 18.51 | 10.37 | 12.53 | 16.01 | 16.81 | 12.10 | 27.24 | 14.11 | 162.87 |
| 1940 | 9.94 | 25.56 | 7.44 | 7.05 | 26.00 | 14.79 | 8.34 | 12.94 | 7.72 | 18.77 | 18.78 | 13.56 | 170.89 |
| 1941 | 8.58 | 1.26 | 7.02 | 14.97 | 26.07 | 15.44 | 11.20 | 18.06 | 10.37 | 12.54 | 11.68 | 9.53 | 146.72 |
| 1942 | 14.43 | 14.39 | 3.84 | 14.47 | 4.87 | 23.38 | 17.35 | 11.11 | 12.50 | 9.34 | 22.78 | 14.32 | 162.78 |
| 1943 | 21.04 | 8.74 | 10.13 | --- | 27.53 | 20.94 | 16.84 | 19.14 | 13.68 | 7.92 | 10.04 | 14.90 | 170.90 |
| Sums | 133.47 | 103.98 | 68.18 | 75.94 | 179.30 | 169.33 | 126.41 | 167.38 | 136.51 | 154.88 | 181.12 | 154.18 | 1650.68 |
| Means | 14.85 | 11.57 | 7.58 | 9.49 | 19.94 | 18.83 | 14.05 | 18.62 | 15.20 | 17.20 | 20.15 | 17.15 | 184.63 |

ATLANTIC OCEAN
LAGO SAN JOSE
Rio Piedras
Carolina
Trujillo Alto
Canovanas
Rio Grande
Loiza
RIO GRANDE
LOIZA
RIO GRANDE DE LOIZA
Penotas Regulating Reservoir
Power Plant No. 2
Grade Conduit
Power Plant No. 1
Penstock
Diversion Dam
Tunnel
Pressure Conduit
El Verde Rain Gage
El Yunque El. 3483
La Mina Rain Gage
Limits of Caribbean National Forest Reserve
Guaynabo
Caguas
Gurabo
Juncos
ISLAND OF PUERTO RICO
LOCATION MAP
SAN JUAN
N
SCALE 1/52000
MILES
EL YUNQUE PROJECT
GENERAL LOCATION PLAN
POWER PROJECT



Elevation in feet
Distance in feet
Caguy Dam
Spillway Crest Elev. 1410'
48" Pipe L=8200'
Surge Shaft
Elev. 1475'±
48" Pipe
L=2600'±
S=.010
60" Pipe, L=1900'
48" Pipe L=1200'
Alternate
River Crossing
Tunnel L=3300'
Penstock 1560 Long
Power Plant ℄ of nozzle
Elev. 310.0±
Power Plant No. 1
48" Pipe
L=9000'
S=.007
℄ Grade Conduit 19,600' long
48" Pipe
L=4600'±
S=.0045
Grande River
42" Pipe
L=6100'±
S=.003
48" Pipe
L=2400'±
S=.0035
Penstock 500' long
Power Plant No. 2 El. 90'±
Canóvanas River
El Verde Dam 25' High
Tunnel, L=700' S=.001
L=1000'±
36" Pipe
L=3900'±
S=.004
Pipe line discharge
at Elev. 1790'±
Pipe line Outlet at Elev. 1770'±
24" Pipe
L=6500'±
S=.008
Pipe line outlet at Elev. 1850'±
18" Pipe
L=1500'±
S=.006
Pipe line intake at Elev. 1856'±
Pipe line intake at Elev. 1942'±
PUERTO RICO WATER RESOURCES AUTHORITY
ENGINEERING AND CONSTRUCTION DIVISION
EL YUNQUE PROJECT
GENERAL PROFILE
OF CONDUITS
SAN JUAN, P.R.
APRIL 2, 1948
DRAWING NO. 2




| AREA NO. | DRAINAGE AREA IN SQ. MILES |
|---|---|
| 1 | 3.50 |
| 2-A | 0.38 |
| 2-B | 0.74 |
| 2-C | 0.61 |
| 3-A | 1.72 |
| 3-B | 0.60 |
| 3-C | 2.06 |
| 3-D | 1.01 |
| 4 | 1.00 |

| AREA NO. | DRAINAGE AREA IN SQ. MILES |
|---|---|
| 1 | 3.50 |
| 2 | 1.73 |
| 3 | 5.39 |
| 4 | 1.00 |
| TOTAL | 11.62 |

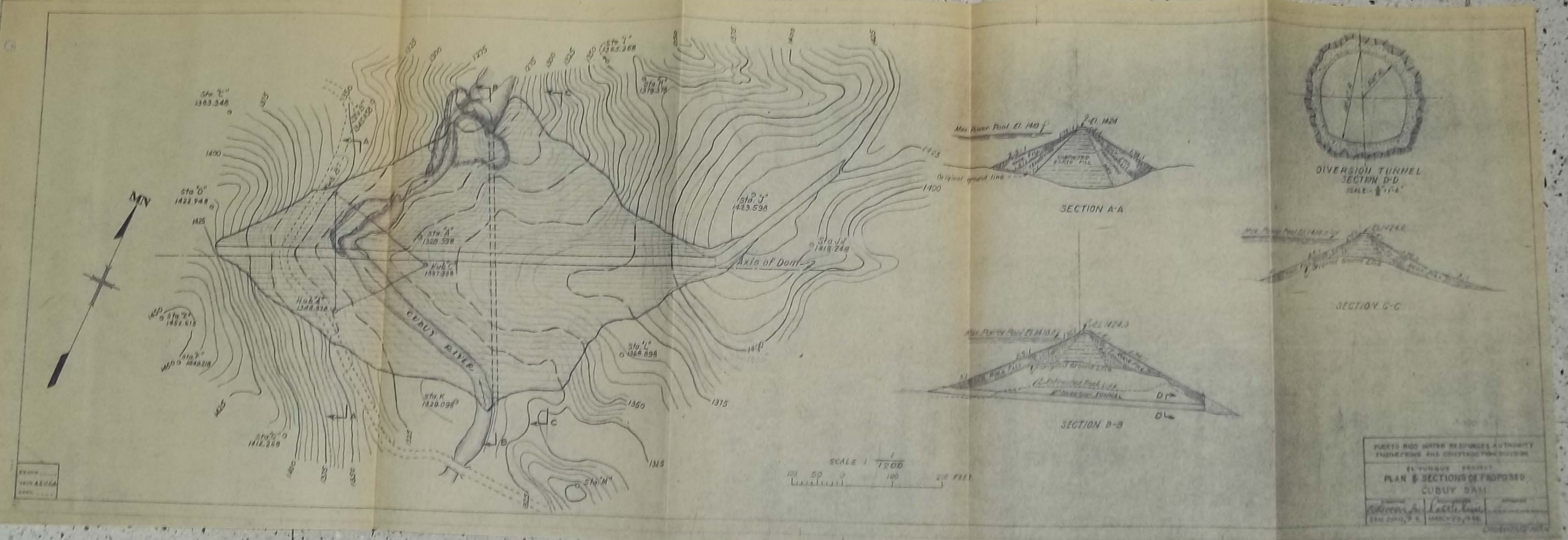
PUERTO RICO WATER RESOURCES AUTHORITY
ENGINEERING AND CONSTRUCTION DIVISION

EL YUNQUE PROJECT

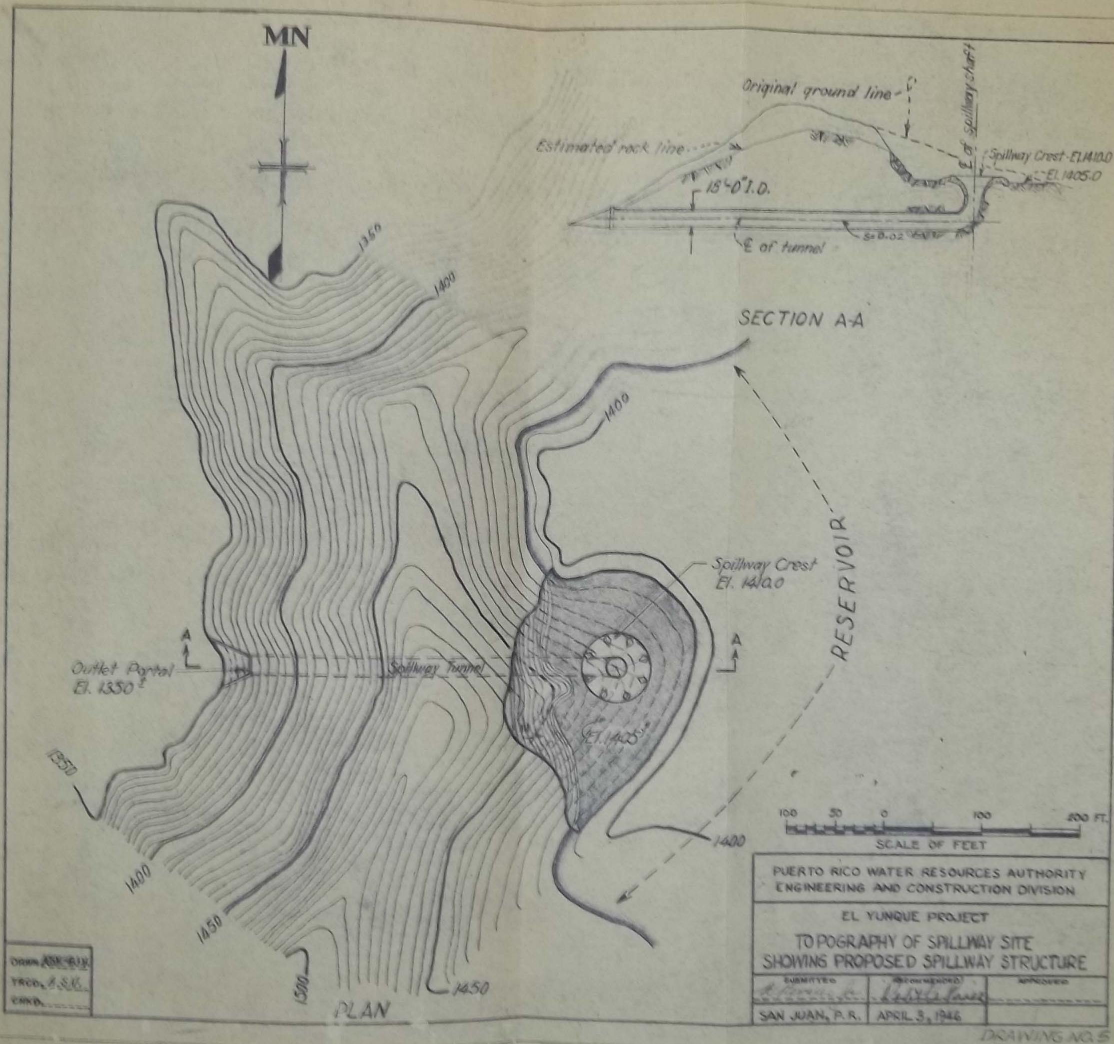
PLAN SHOWING WATER SUPPLY AREA

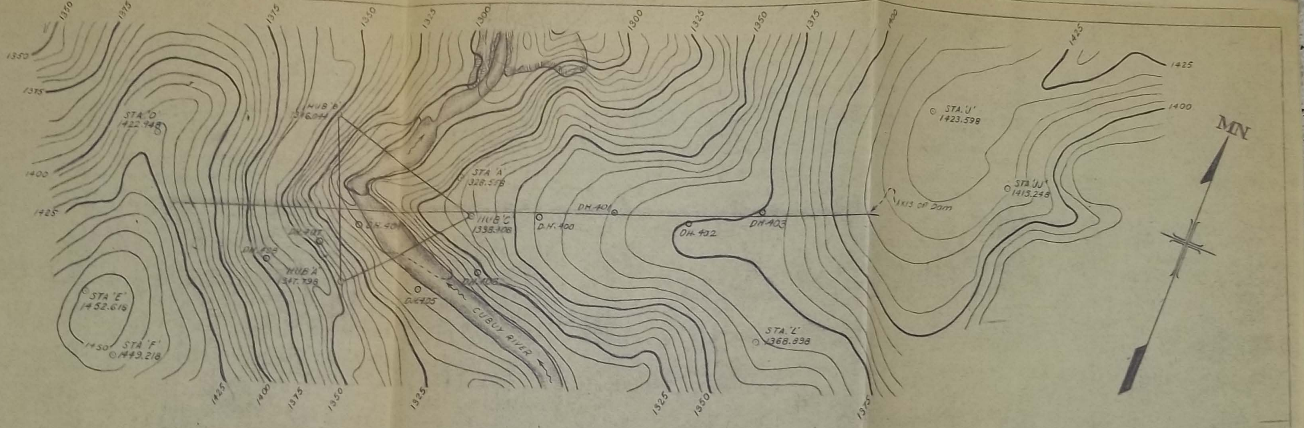
SAN JUAN, P.R. | MARCH 15 1946

DRAWING NO. 3

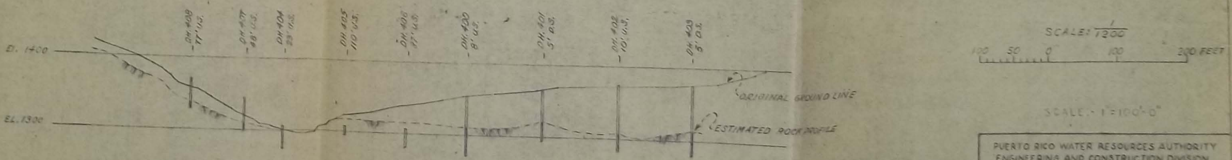


MN
Sta "C" 1363.348
Sta "D" 1423.948
Sta "A" 1328.598
Hub "C" 1357.328
Hub "A" 1348.338
Sta "E" 1452.613
Sta "I" 1365.268
Sta "H" 1379.378
Sta "J" 1423.598
Sta "L" 1368.898
Sta K 1329.098
Sta "M"
Axis of Dam
CUBUY RIVER
SCALE 1/1200
100 50 0 100 200 FEET
Max Power Pool El. 1418
El. 1424
Original ground line
SECTION A-A
SECTION B-B
DIVERSION TUNNEL
SECTION D-D
SECTION C-C
PUERTO RICO WATER RESOURCES AUTHORITY
ENGINEERING AND CONSTRUCTION DIVISION
EL YUNQUE PROJECT
PLAN & SECTIONS OF PROPOSED
CUBUY DAM
SAN JUAN, P.R.


MN
Original ground line
£ of Spillway shaft
Estimated rock line
Spillway Crest-El.1410.0
El. 1405.0
18'-0" I.D.
S=0.02
£ of tunnel
SECTION A-A
1350
1400
1450
1500
RESERVOIR
Spillway Crest
El. 1410.0
El. 1405
Outlet Portal
El. 1350±
Spillway Tunnel
A
PLAN
100 50 0 100 200 FT.
SCALE OF FEET
PUERTO RICO WATER RESOURCES AUTHORITY
ENGINEERING AND CONSTRUCTION DIVISION
EL YUNQUE PROJECT
TOPOGRAPHY OF SPILLWAY SITE
SHOWING PROPOSED SPILLWAY STRUCTURE
SUBMITTED
RECOMMENDED
APPROVED
SAN JUAN, P.R.
APRIL 3, 1946
DRWN.
TRCD.
CHKD.
DRAWING NO. 5




PLAN




PROFILE ALONG AXIS OF DAM

SCALE:- 1" = 100'-0"

DRAWN R.C.A.P.S.
TRCD. A.O.R.
CHKD.

| PUERTO RICO WATER RESOURCES AUTHORITY<br>ENGINEERING AND CONSTRUCTION DIVISION | | |
|---|---|---|
| EL YUNQUE PROJECT<br>CUBUY DAM SITE<br>FOUNDATION PLAN SHOWING DRILL HOLES AND ROCK PROFILE | | |
| [signature] | [signature] | |
| SAN JUAN, P.R. | MARCH 12, 1946. | |

DRAWING No. C